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Original Article

Large Steel Tank Fails and Rockets to Height of 30 meters – Rupture Disc Installed Incorrectly

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ABSTRACT

At a brewery, the base plate-to-shell weld seam of a 90-m^3 vertical cylindrical steel tank failed catastrophically. The 4 ton tank "took off" like a rocket leaving its contents behind, and landed on a van, crushing it. The top of the tank reached a height of 30 m. The internal overpressure responsible for the failure was an estimated 60 kPa. A rupture disc rated at < 50 kPa provided overpressure protection and thus prevented the tank from being covered by the European Pressure Equipment Directive. This safeguard failed and it was later discovered that the rupture disc had been installed upside down. The organizational root cause of this incident may be a fundamental lack of appreciation of the hazards of large volumes of low-pressure compressed air or gas. A contributing factor may be that the standard piping and instrumentation diagram (P&ID) symbol for a rupture disc may confuse and lead to incorrect installation. Compressed air systems are ubiquitous. The medium is not toxic or flammable. Such systems however, when operated at "slight overpressure" can store a great deal of energy and thus constitute a hazard that ought to be addressed by safety managers.

1. Introduction

Vertical cylindrical tanks used for the bulk storage of liquids at ambient (i.e., atmospheric) pressure or minimal overpressure are ubiquitous in industry. Catastrophic tank failure is rare. Even though the likelihood is low, the scenario may contribute significantly to the risk as the consequences can be considerable [1].

The sheer force of a sudden release of large amounts of liquid can propel the walls of a ruptured tank onto other tanks or structures and cause domino knock-on failures [2]. The sudden gush of liquid can make dikes or bunds overflow or otherwise overpower barriers erected to provide 100% volumetric capacity in the event of tank leakage [3,4]. Many tanks hold toxic or hazardous substances that, if released, could cause harm to humans or the environment.

A review of catastrophic failures of bulk liquid storage tanks has been provided in the literature [1], and new incidents are occasionally reported [5,6]. The cases described below were selected because they may not be well known in English-language publications.

During the severe winter of 1959 there was a fuel oil tank failure in Skærbæk, Denmark, when a 10,000 m^3 atmospheric tank with heavy fuel oil failed catastrophically with a "thunderous bang." The flood of warm fuel oil overtopped the bund and damaged a wall at the nearby power station before the viscous fluid cooled and solidified. Very little information is available but it appears that the failure was caused by low-temperature brittle failure of the steel shell.

In 2011 there was a fish silage tank failure in Aabenraa, Denmark, when a tank collapsed with a loud deep rumble, which resembled the sound produced by large metal sheets being shaken. The sudden release of 6,000 tons of viscous, acidic fish silage produced a 14-m high tidal wave, some of which washed over the bund wall, knocked over trees, and damaged parked cars before arriving at a nearby small community of dwelling houses and allotments and the harbor. Several neighboring tanks in the common bund were damaged and one tank that contained soya bean oil started leaking. There were no human casualties. The topsoil of the affected nearby properties was replaced. The tank failure was otherwise characterized as an incident resulting in a widespread unpleasant stench, but no significant harm to the environment. The emergency responders' uniforms had to undergo specialized cleaning, a treatment that unfortunately could not be extended to the vehicles,

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which continued to have an unmistakable odor of fish [7]. Fish silage is not a regulated substance and not classified as hazardous. The tank was inspected in 2008 by a specialist tank inspection company and given a clean bill of health until 2018. After the tank collapse, the tank owner took the tank inspection company to civil court for professional malpractice. The civil liability case is currently *sub judice* and details are unavailable.

In 2005 there was a sulfuric acid tank failure in Helsingborg, Sweden, when the bottom-to-shell weld of a steel tank failed catastrophically and released 8,900 m^3 of 96% sulfuric acid over an estimated 2.5–4 minutes. The sudden release of the tank contents produced a partial vacuum that caused the roof and shell to implode. Large quantities of acid ended up in the harbor where the acid reacted with seawater to produce hydrogen chloride. It is believed that within a few minutes "tens of tons" of gaseous and aerosol hydrogen chloride formed a toxic cloud that extended to a height of 70 m. Consequence modeling indicates that concentrations that could produce severe irritation, extended 3–4 km from the site. After ~1 hour, when the cloud had drifted ~10 km, concentrations had likely diluted to a safe level. There were no casualties. The cause was the rupture of a 6 bar 600-mm diameter reinforced concrete pipeline 1 hour earlier, which provided seawater to a nearby industrial complex for cooling purposes. The seawater line passed close to the tank and the pipeline rupture liquefied the soil and produced a cavity, which undermined the tank and led to foundation instability [8].

This article is concerned with tanks that operate under very slight overpressure rather than tanks operated at ambient atmospheric pressure. This includes tanks that are gas blanketed, inerted, or otherwise have a controlled headspace. For the purposes of this article, we define very slight overpressure as 50 kPa (i.e., 0.5 bar or ~7.4 psig), which is the limit set in the European Pressure Equipment Directive (PED) [9]. The Directive applies to the design, manufacture, and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure > 50 kPa. It is common practice in industry to install a rupture disc or another overpressure safety device rated at < 50 kPa. A vessel thus protected, is not then classified as a pressure equipment component and avoids the need to fulfill the rather onerous requirements of the Directive for written documentation and other formalities.

Tanks originally designed for ambient pressure may be modified to operate at slight overpressure. This change in operation may occur for several reasons such as vapor recovery, reduction of volatile organic compound emissions, and odor control. This article argues that systems operated at "very slight overpressure" can store a great deal of energy and thus constitute a hazard that may not be fully appreciated. The tank may fail catastrophically, shoot into the air, and spill its contents. This article draws specific attention to the fact that a rupture disc overpressure safety device can be compromised if installed incorrectly.

2. Materials and methods

2.1. Process description

2.1.1. Surplus yeast

During the fermentation of beer, the yeast cell mass increases three- to six-fold. Much of this yeast is collected as surplus yeast and shipped to external processors for conversion into products such as protein pills for animal feed [10].

The bottoms from beer fermentation tanks is one source of surplus yeast. Surplus yeast is also collected from other waste streams and separated by filters or centrifuges. The term "yeast slurry" technically refers only to dehydrated yeast that has been reslurried; however, this article uses the term for any type of surplus yeast.

2.1.2. Indoor collection vessel

At a Danish brewery, surplus yeast slurry is first collected in an indoor yeast collection vessel and then transferred to an outdoor storage tank (Fig. 1).

The indoor yeast collection vessel has a volume of 10 m^3 and is connected to the brewery's sterile compressed air system and maintained at 100 kPa overpressure. When an operator initiates the transfer of yeast slurry, a bottom outlet valve opens and the compressed air presses the viscous yeast slurry into a 90-m^3 outdoor storage tank. The control logic closes the bottom valve when a signal from a liquid level switch low (tuning fork/vibrating fork type) indicates that the vessel is empty.

2.1.3. The incident outdoor storage tank

The outdoor storage tank was constructed in 1973. It was a vertical, cylindrical tank with a height of 8 m; diameter, 3.8 m; gross volume, 96.5 m^3; working volume, 90 m^3; stainless steel type 304 plate thickness, 3 mm; and mineral wool insulation, 200 mm in thickness. The floor plate was sloped towards the outlet nozzle.

The floor plate rested on a sloping steel structure that was supported by a concrete base. A circumferential steel profile at the base of the supporting steel structure served as the point of attachment for the shell skirt plate of the tank.

Only rudimentary construction details are available because of the age of the tank. Information on construction code, maximum allowable working pressure, specification sheets for the construction materials, and engineering drawings are absent. The tank appeared to have been designed for liquid storage at ambient pressure. For many years, the tank was used for the temporary storage of an intermediate brewery liquid and was indeed operated at ambient pressure. Approximately 5 years earlier, the tank was moved and the service changed to surplus yeast.

Surplus yeast is a biologically active material and an excellent medium for the growth of unwanted microbes. Occasional nuisance foaming is a concern. The storage tank was therefore modified to operate at a pressure of 10 kPa to suppress foaming. A spring-operated pressure valve was set at 20 kPa (g) to allow tank breathing during loading when the incoming liquid reduces the headspace vapor volume in the tank. A rupture disc overpressure relief device (a.k.a. bursting disc), was installed in the tank's 2-inch vent line. The vendor specification sheet reports a burst pressure range of 43–49 kPa at 22°C.

The change in tank service was likely viewed as a rather trivial engineering task. It is probably fair to assume that the handling of a waste stream like surplus yeast from brewing, commands minimal attention by management.

2.2. The incident

2.2.1. Witness statement

On the day of the incident, the outdoor yeast storage tank had recently been emptied. It was receiving its first batch of fermentation tank bottoms from the yeast collection vessel, probably no more than 3 m^3.

Shortly before the tank failure, two refrigeration technicians employed by an external contractor arrived to service a large ammonia-cooling unit on the roof of the adjacent building. They parked their van next to the outdoor yeast storage tank, entered the building, and climbed the stairs to the roof. Immediately after passing through a doorway in a 3-m high noise protection wall on the roof, they heard a sudden dull "*poof*". They turned around and saw the storage tank rising vertically in the air. The base of the tank